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THE SELECTION, INSTALLATION AND TEST OF A 1,000,000 GALLON MOTOR DRIVEN CENTRIFUGAL PUMP

BY S. R. BLAKEMAN

INTRODUCTION

It may be of interest to mention first a few of the characteristics of the plant in which this pump test was made, as well as give a brief outline of the history of the plant and the conditions that necessitated the purchase of the above pumping unit.

The city of Dyersburg, Tennessee, owns and operates its own water and light plant, the origin of which dates back to 1903, at which time it was taken over from private ownership. Immediately after the purchase of this plant by the city, steps were taken to improve the plant and distribution system, so as to give good service at minimum cost; and at the present time it is safe to say that there are but few plants of its size that have as low water rate as the Dyersburg plant, everything being considered.

The plant is located on the banks of the Forked Deer River, a small stream, the turbidity of which runs very high throughout the year, and, of course, it was natural that the first supply should be taken from this stream; but after some experience with this supply, which was not at all satisfactory, it was decided to change to well water, thereby eliminating filtration and the extra expense connected therewith. However, upon the completion of several wells that were practically drilled in the river, it was at once seen that this water contained quite an amount of iron in solution, as ferrous carbonate, which would also require treatment and filtration. At present the total amount pumped is taken from deep wells, treated and filtered, excellent results being obtained.

The original design of the plant included two 10 x 16 x 10 $\frac{1}{4}$ x 10 inch Worthington Compound Pumps, one of these being used to lift water from the wells into the subsiding tanks for treatment, whence it flowed to the filters; the other pump being used to deliver water from the clear well directly into the mains against a pressure

of 80 pounds per square inch. Later, another steam pump was added to the plant having a capacity of 1,000,000 gallons per twenty-four hours. This pump was expected to act as an auxiliary for the other pumps.

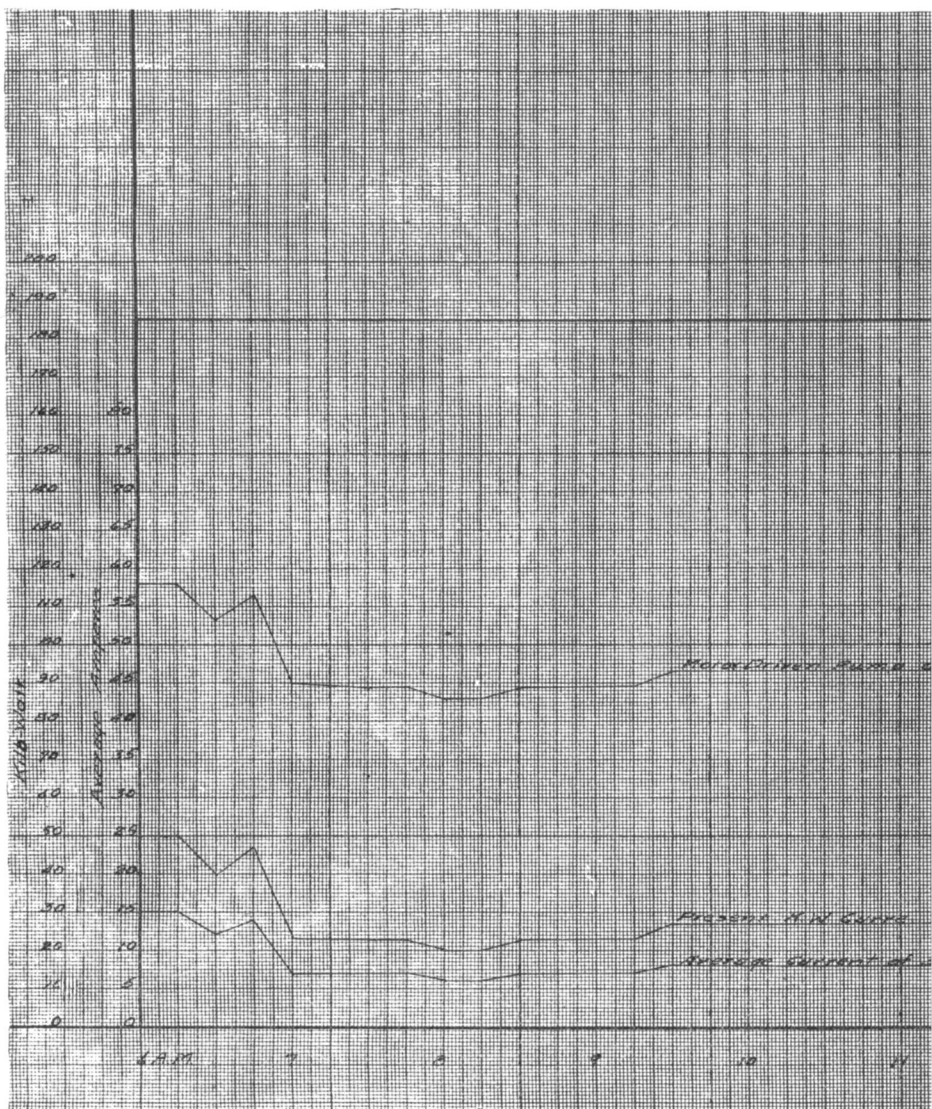
About the time the last mentioned steam pump was installed, two new engines and generators were installed having an aggregate capacity of 435 kilowatts. These replaced the original units, of much smaller size, the load on the station having exceeded their capacity. With the new equipment installed, the plant had to be operated for a large part of the time on very small load, below one half the rated capacity of the units.

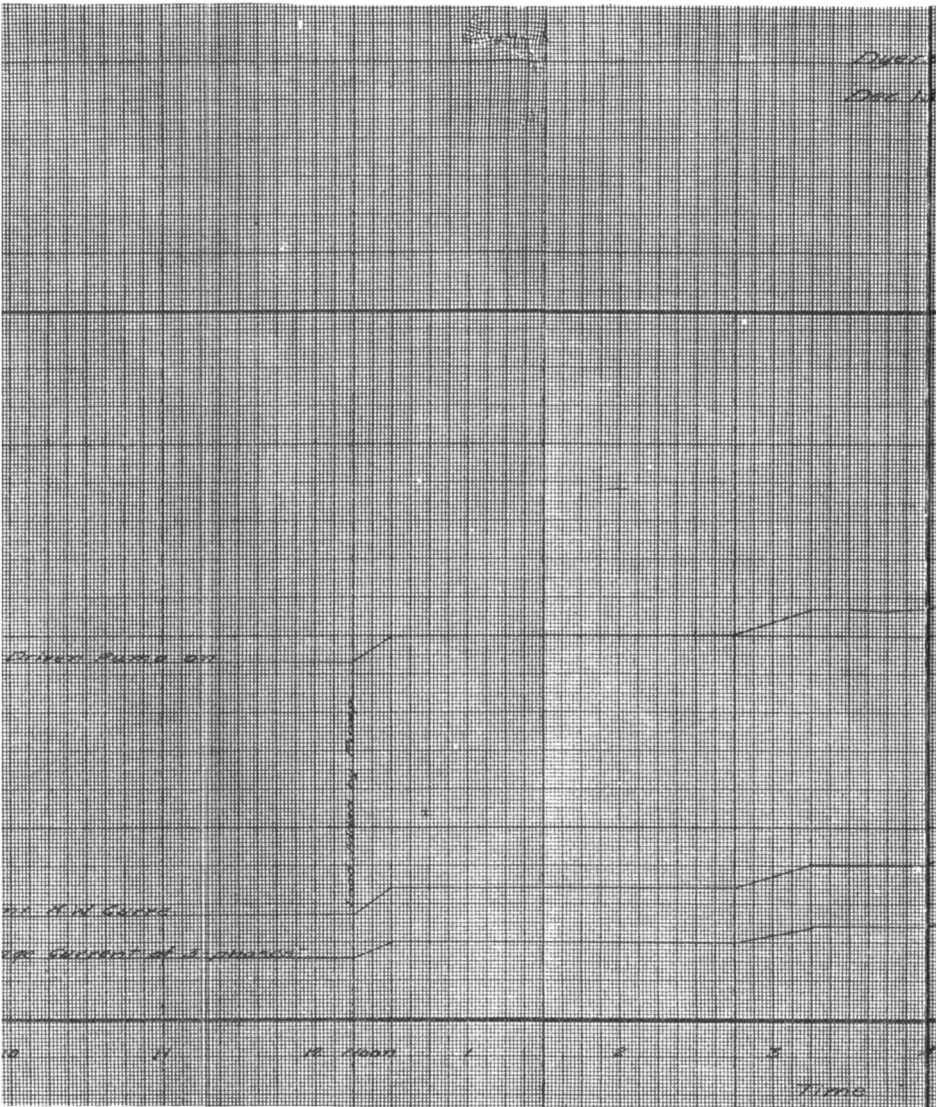
The above engines being of the four valve, non-releasing Corliss type it was naturally to be expected that the steam consumption would be very high at light loads. The only relief for the above condition was additional load, which, of course, could only be obtained from a source outside of the plant and the installation of motor driven pumping units in the plant. With the addition of the average outside load, it was naturally to be expected that the load conditions would show quite a variation, the load curve rising to a peak when the lighting load was a maximum, during the early hours of the night, and gradually falling off and becoming a minimum during the later hours of the night. A typical load curve showing these conditions is shown on Plate I. Readings of the switchboard instruments were taken every fifteen minutes, to show small variations on this curve, the ordinates of these curves being in k.w. and the abscissa time, the power factor for each curve being assumed as the same.

The dotted curve shows variation of the load as taken on December 15, 1914, after a 6-inch motor driven volute pump had been installed, to replace one of the 750,000 gallon steam actuated pumps, this pump being designed to deliver 700 g.p.m. against a total head of 45 feet.

The load curve shown by solid line, Plate II, was taken from data obtained on December 24, 1915, after the motor driven turbine pump had been placed in operation. These curves show plainly the improved conditions of the load due principally to the addition of this pump.

Another feature, not to be overlooked, and which is shown on this curve, is how well the motor driven pump adapts itself to the load conditions of the plant. Since the installation of the turbine





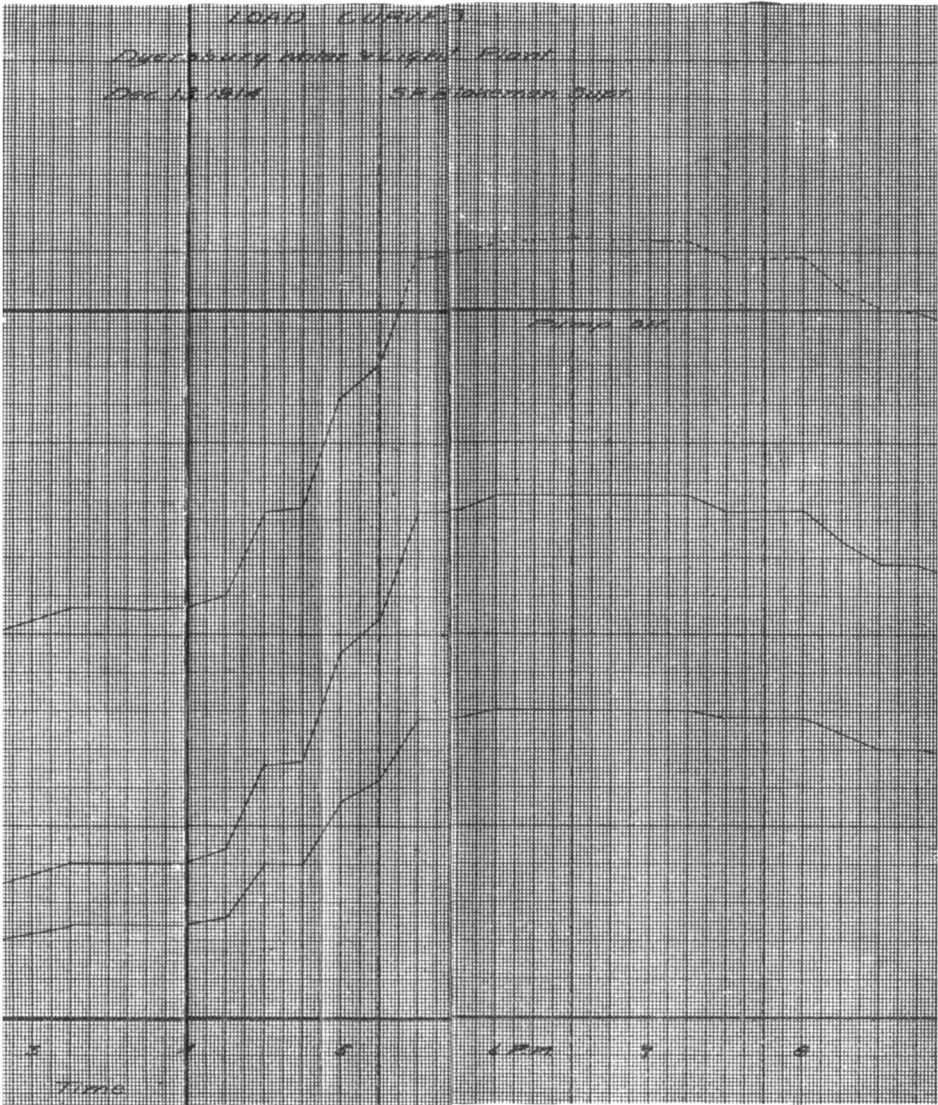
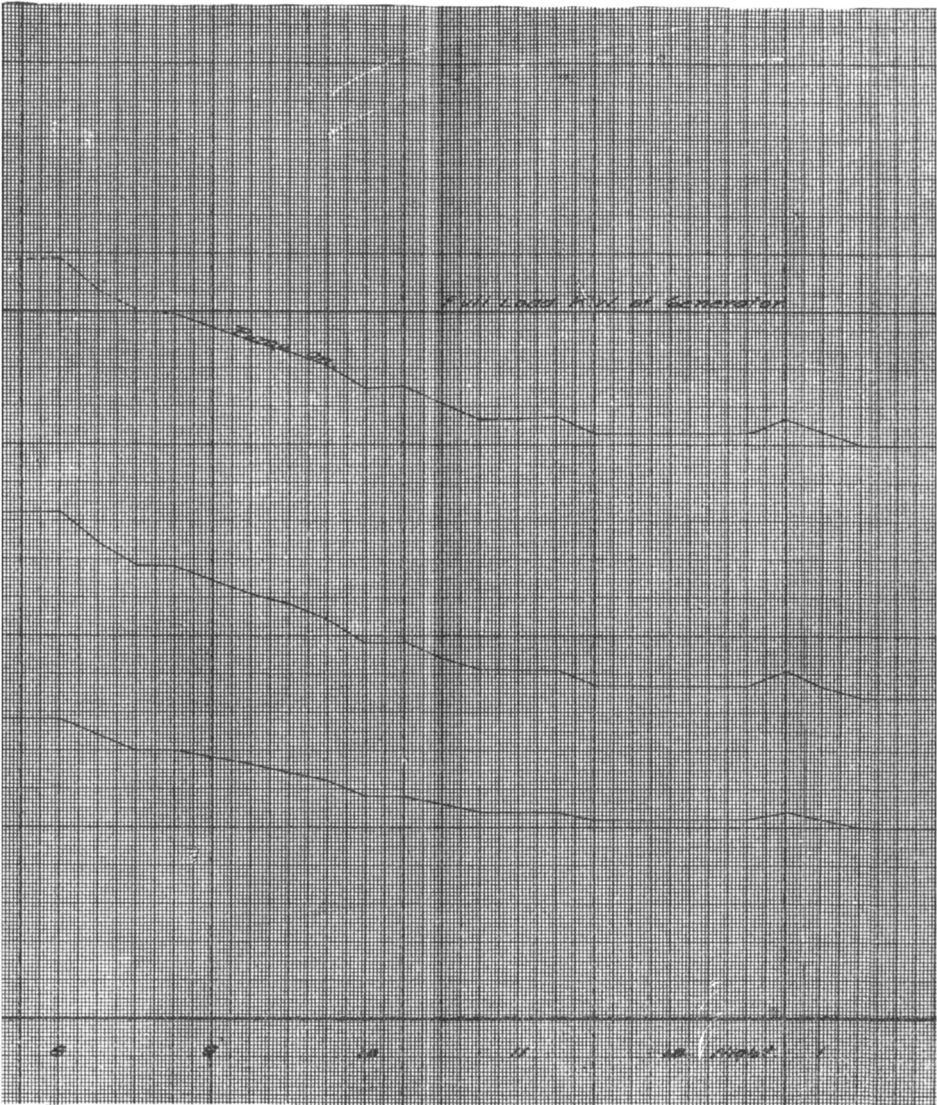
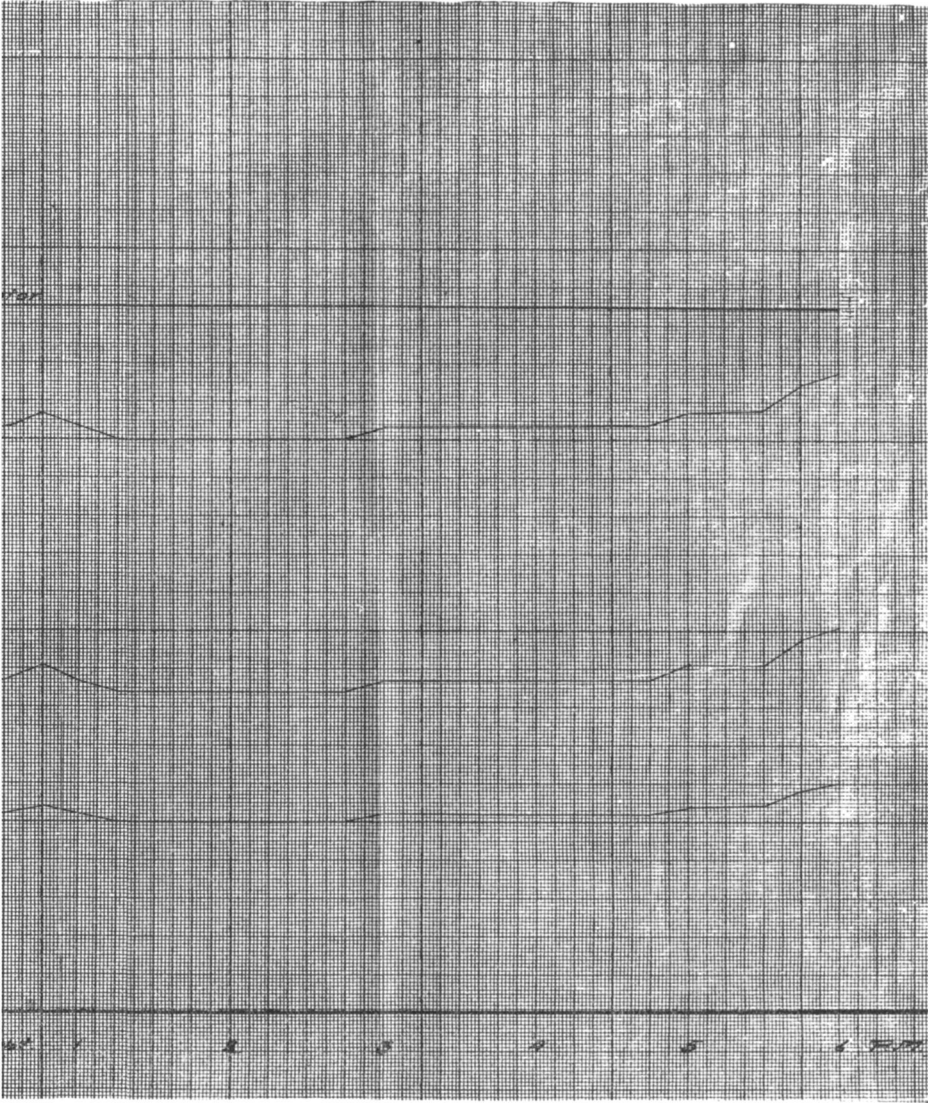
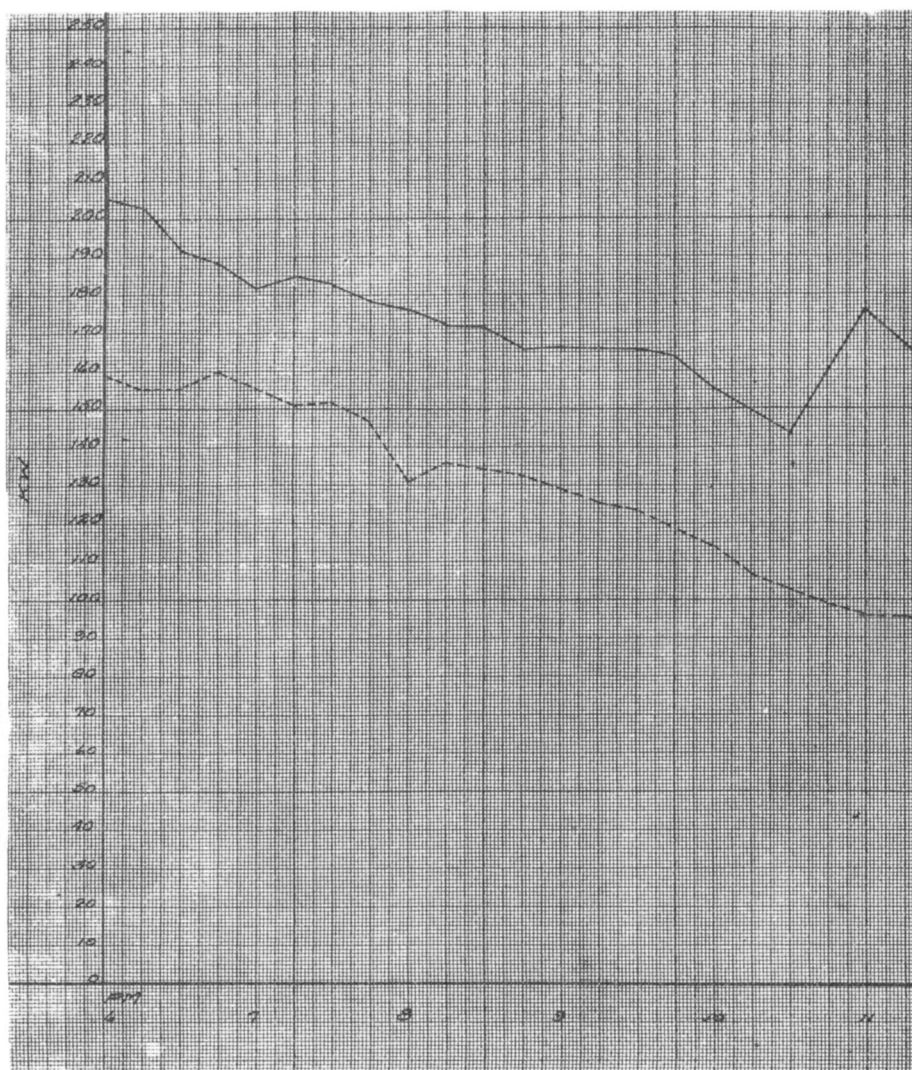
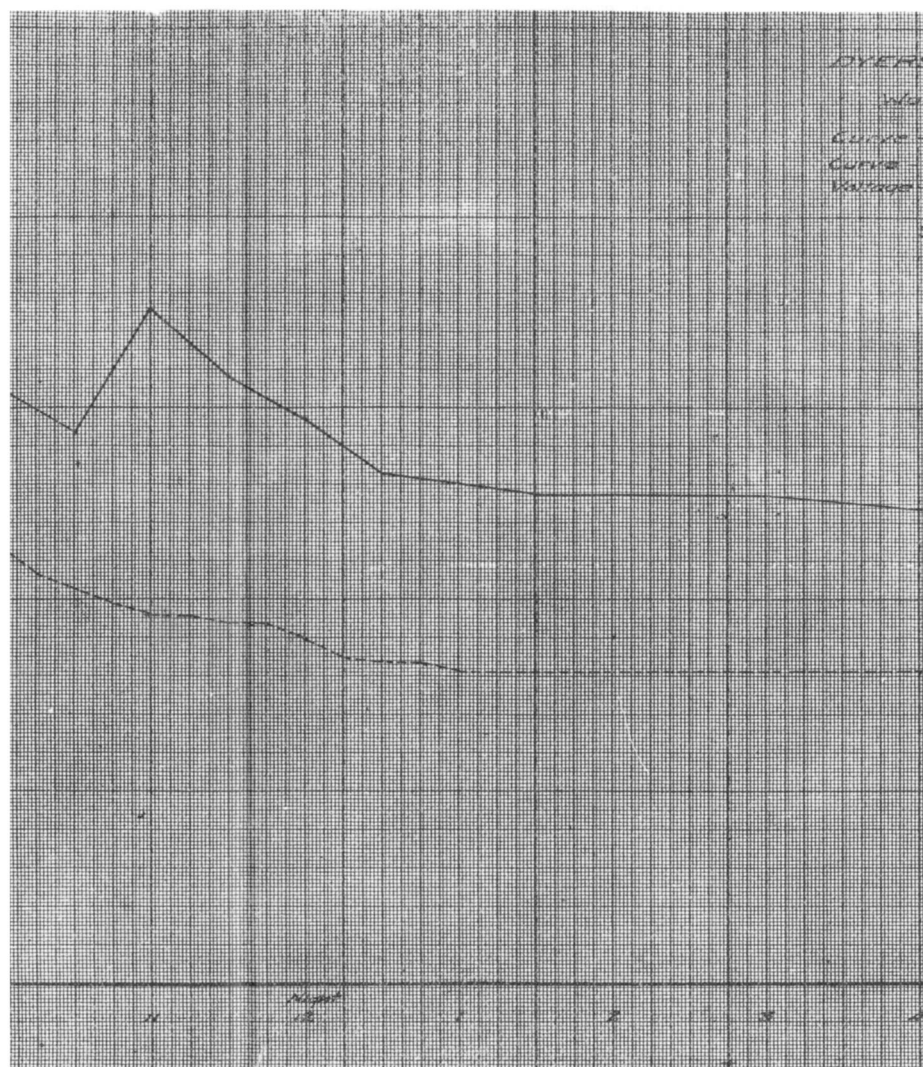


PLATE 1









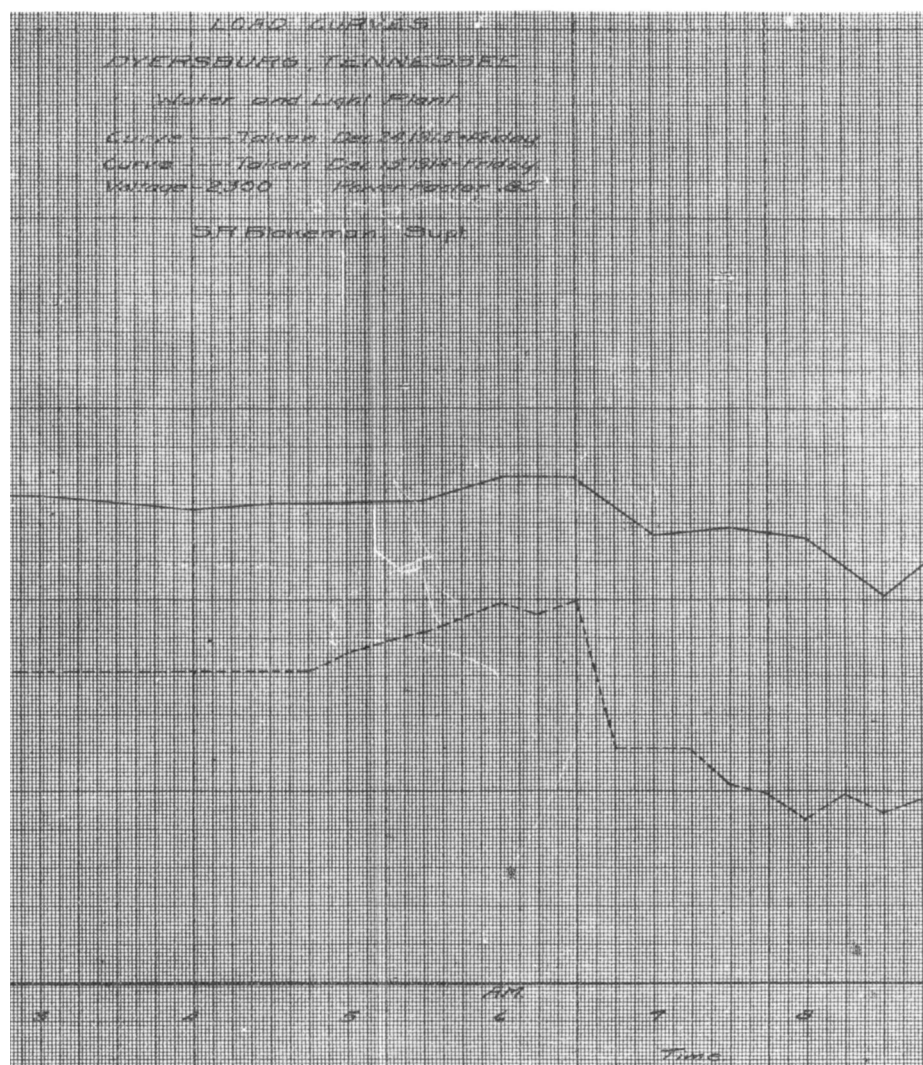
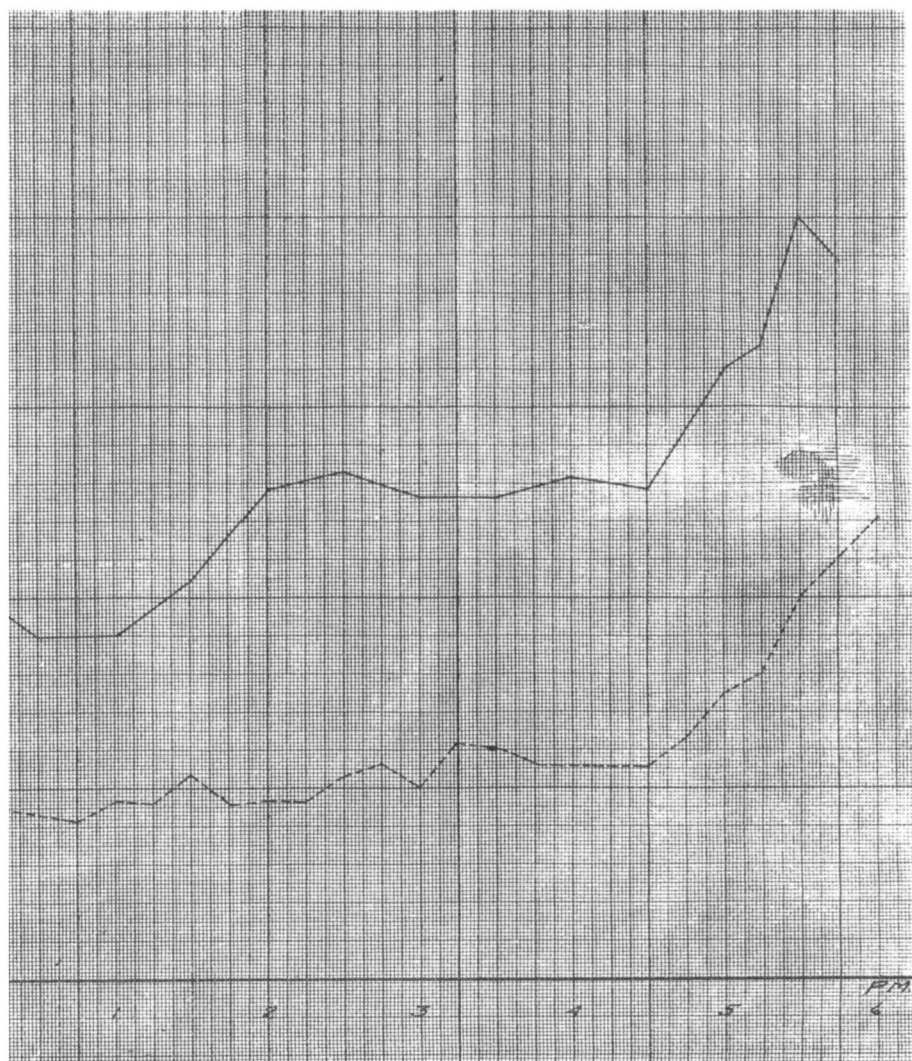


PLATE II





pump, a motor driven triplex boiler feed pump was installed, thereby eliminating the last steam actuated pump in the plant so far as regular operation is concerned.

Each of the above pumps is provided with a recording wattmeter. These meters are read every twenty-four hours, and from this information, the kilowatt hours consumed by each pump are computed. There is also a recording wattmeter on the switch board, recording the total output from the generator, the water meter, in the discharge from the turbine pump, giving us the total gallons pumped.

All this information, as well as a record of each ton of coal burned, is entered on the log sheet at the plant. From this, the pounds of coal required per k.w.h. generated, and per 1000 gallons pumped are figured, and properly entered.

A recording pressure gauge indicates the variation in pressure throughout the day. Plate III is an average gauge chart showing how uniformly the pressure is maintained throughout the day. It will be seen from this chart that the pump was shut down at 5.30 p.m., the pressure being 85 pounds per square inch. The electrical load, at this time, was beginning to reach a maximum. At 11.00 p.m. the curve shows the pump again running, the electrical load having reached nearly a minimum, the loss in pressure during this time amounting to only 5 pounds. A good feature of this installation is the fact that in the summer when the electrical load is minimum, the pumping load is maximum, and in the winter the reverse is true.

From these curves, it will be seen that the load factor of the station was very low. The guarantees on steam consumption for the engines when installed, were 32 pounds per i.h.p. hour, at one-fourth load and approximately twenty-four pounds, per i.h.p. hour when operating from one-half to full load. From this, assuming the steam consumptions are in the proportion as shown above, by adding sufficient load the steam consumption could be reduced to eight pounds per i.h.p. hour, and the efficiency of the generators increased from 5 to 10 per cent.

In the fall of 1914 an appraisal of the water works and electric light plant was made, from which the amount of fixed charges each carried per twenty-four hours was figured. Next, a series of tests were made, extending over a period of more than a week, during which twice the amount of fuel, labor, oil, etc., required to pump 1000 gallons of water was determined; in this data, were also included the kilowatt hours supplied the volute pump, and also the lime used

in the filtration department. After working out the above tests, the average cost of pumping 1000 gallons, including capital charges and depreciation on machinery, was found to be \$0.064. The average cost of generating a k.w.h., including capital charges and depreciation, was found to be \$0.028. The latter charge had to be

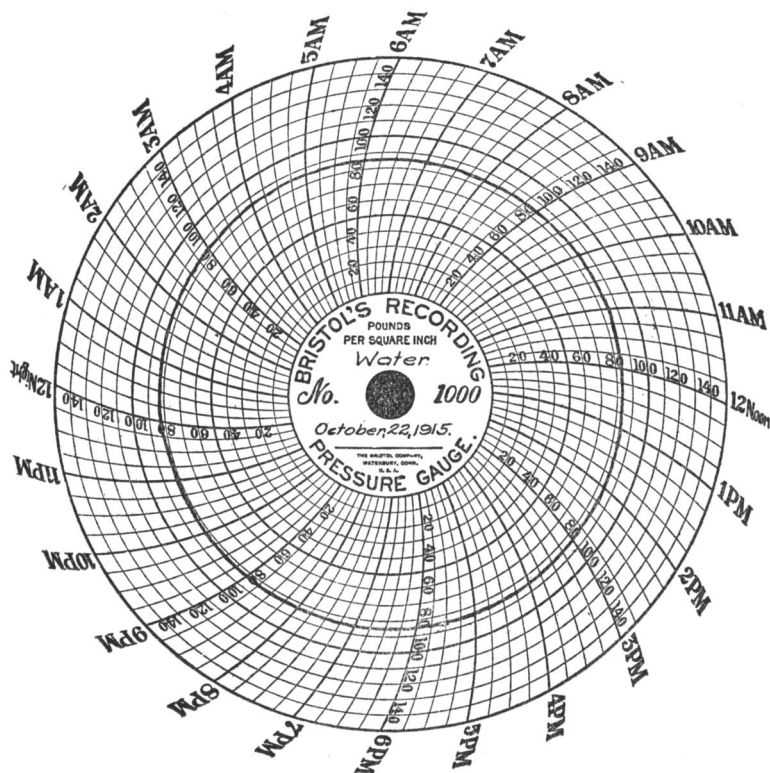


PLATE III

determined in order that the cost of operating the motor driven volute could be found.

With all of the above information available, it was at once seen that by the addition of a motor driven pump the economy of the plant could be materially increased. However, before making any final decision it was thought wise to weigh all matters well and see how a triple expansion pumping engine would compare with the motor driven turbine pump; theoretically it was shown that the

motor driven pump would effect a saving over the pump then in operation of 511 tons of coal per year, which at \$1.75 per ton delivered in the boiler room would amount to an annual saving of \$894.25.

While the above showed the theoretical saving that would be effected by this installation, accepting the guarantees on the engines and generators as correct, it does not show the total amount saved, such as oil, maintenance, packing, etc., over the steam actuated pump, nor does it give a fair comparison of the two units.

The following formulae will bring out the above more plainly.

$$C = \frac{A \times W \times H \times P}{D} + F(I + D) + L + M$$

for the triple expansion pumping engine and

$$C = \frac{A \times W \times H \times K}{2,655,000 \times \text{overall efficiency of pump and motor} + F(L + d) + L + M}$$

for the motor driven pump.

In the above formulae:

C = Total cost of pumping per year.

A = Gallons pumped per year.

W = Weight of a gallon of water.

P = Cost of steam per thousand pounds.

H = Average total head pumped against.

D = Average duty in foot pounds per thousand pounds steam.

F = Total investment.

i = Rate of interest on investment.

d = Rate of depreciation.

M = Yearly cost of miscellaneous expenses of operation.

L = Yearly cost of operating labor.

K = Cost of power per k.w.h.

Triple expansion pumping engine

A = 219,000,000 gallons

W = 8.33 pounds

H = 175 feet

P = .175

D = 78,000,000

F = \$5780

Motor driven turbine pump

A = 219,000,000 gallons

W = 8.33 pounds

H = 175 feet

K = .02

D = 2,655,000 foot pounds

F = \$1500

<i>Triple expansion pumping engine</i>	<i>Motor driven turbine pump</i>
$i = 5$ per cent	$i = 5$ per cent
$d = 5$ per cent	$d = 5$ per cent
$L = \$1200$	$L = \$1000$
$M = \$200$	$M = \$50$

Then the formulae:

$$C = \frac{A \times W \times H \times P}{D} + F(i + d) + L + M,$$

gives for the steam pump,

$$C = \frac{219,000,000 \times 8.33 \times 175 \times .175}{78,000,000} + \$5780(5\% + 5\%) + \$1200 + \$200$$

or $C = \$2694.25$

For the motor driven turbine pump, the formula was used:

$$C = \frac{A \times W \times H \times K}{2,655,000 \times \text{overall efficiency of pump and motor} + F(i + d) + L + M}.$$

Then, by substitution,

$$C = \frac{219,000,000 \times 8.33 \times 175 \times .02}{2,655,000 \times 0.61} + \$1500(5\% \text{ and } 5\%) + \$1000 + \$50$$

or $C = \$1203.94$

From this it will at once be seen that there would be an annual saving in the cost of pumping by the motor driven turbine pump over the triple expansion pumping engine of \$1490.31; proving that the motor driven turbine pump, everything being considered, would effect the greater saving.

The following specifications were adopted before asking for bids.

SPECIFICATIONS FOR MOTOR DRIVEN PUMP FOR DYERSBURG WATER AND LIGHT
DEPARTMENT, DYERSBURG, TENNESSEE

Capacity 700 g.p.m. Head 230 feet

1. The casing must be so arranged that it can be opened and the impeller and all working parts removed without breaking the suction and discharge connections to the pump and without disassembling the working parts themselves or disturbing the main pump casing or bed plate.

2. When this pump casing is opened all passages must be accessible.

3. The parts shall be of such material and so arranged that corrosion caused from long use will not render dissembling difficult.

4. The pump casing shall be so designed and built that it will be amply strong to withstand the pressure the pump was designed for, and which at maximum head the pump is capable of enveloping.

5. All rotating parts that will come in contact with water must be constructed of bronze, to prevent corrosion.

6. There shall be ample room for packing the stuffing boxes and the shaft must be protected from wear by the use of a bronze sleeve.

7. The builder must furnish with his proposition a blue print, showing the characteristics of the pump that he proposes to furnish, this showing the efficiencies, head capacity and brake horse power characteristics that he will guarantee when the pump is tested on the foundation at the station. After the pump has been built, it must be tested in the builder's shop and a certified copy of this test must be furnished, including the characteristics and the actual data obtained from the test.

8. The bearings must be so constructed that they may be removed without disturbing any part of the pump except the bearing caps.

9. The shaft must be rigid and perfectly balanced and protected from direct contact with the water.

10. All parts shall be made on an interchangeable basis so that they will fit properly and may be quickly obtained.

11. The pump must be equipped with a flexible coupling. The motor to be shipped to the company manufacturing the pump and mounted at the expense of the pump maker.

12. The price of the pump to be f.o.b. cars at our station.

13. With the pump proposition must be furnished the following: Size of suction, size of discharge, revolutions per minute, number of stages, weight of pump, delivery in days after receipt of order and terms of sale.

14. Foundation plans must be furnished upon receipt of order.

These specifications were sent to fifteen manufacturers of centrifugal pumps.

ANALYSIS OF BIDS

As soon as bids were received, they were tabulated as shown on the attached "Analysis Sheet," Plate IV. From the characteristic curve sheet, the efficiency, head and brake horse power were determined for discharges of 100, 200, 300, 400, 500, 600, 700 and 800 gallons per minute, the values being entered as shown on the table.

It may be seen from the load curve sheet that the load shows considerable variation in twenty-four hours, and, as the duty of this unit is to help build up the offpeak load, it will be seen that for certain periods of the day the discharge would have to be throttled to reduce the load on the engine or the pump be shut down, especially when the small generator was in operation, to keep the standpipe practically full at all times. Therefore, it was important that the average efficiency of the pump from 200 to 700 g.p.m. be as high

as possible. A column on the analysis sheet is so tabulated. In other words, it was desired to secure a pump that would show a flat efficiency curve. Some very interesting examples of this are shown on the analysis sheet, for instance, one pump shows a maximum efficiency of 69 per cent at 700 g.p.m. and only 14 per cent efficiency at 100 g.p.m. and an average efficiency of only 47.7 per cent. It will be seen that pump "F" shows an extra high efficiency, but failed to comply with the specifications. Several of the pumps listed did not conform with the specifications, but they were listed to show their other features.

The cost of foundation and the installation charges were estimated to be the same for each pump. It can readily be seen why pump "A" was bought, also motor "P."

In order to reduce transmission losses and transformer expense to a minimum it was decided to make use of a 2300 volt, three phase motor. Had a 220 volt motor been selected, the initial cost would have been greatly increased. A comparative cost of the two is:

Price of 2300 volt motor with starting box.....		\$439.47
Price of 220 volt motor with starting box.....	\$627.26	
Price of 3-25 k.w. transformers	548.88	
Labor installing above.....	20.00	
Total.....	\$1,196.14	\$439.47

This shows a saving in initial cost of \$756.67 in favor of the 2300 volt motor. In addition to the above, taking into consideration the three transformers, there would be effected an annual saving in interest on the investment, depreciation and transmission losses of approximately \$188.28. It would then be evident that the high voltage installation would be the most economical.

On the analysis sheet, there will be seen an analysis of three motors, showing the efficiencies and power factors for $\frac{1}{2}$, $\frac{3}{4}$, full load and 25 per cent overload. Motor "P" was selected, due to the fact that it was thought better adapted for the work than either of the others. Motors "S" and "P" show practically the same efficiency and power factor for different loads.

The progress of the centrifugal pump has been held back to a certain extent, due to the fact that many mistakes are made in their selection, and more care is required in this type of pump than any other, especially regarding the subject of head. In the installa-

Analysis of a proposed motor driven centrifugal pump instal

MAKE OF PUMP	MAKE OF MOTOR	SUCTION HEAD	DISCHARGE HEAD	TOTAL HEAD	G. P. M.	SIZE OF SUCTION	SIZE OF DISCHARGE	R. P. M.	TYPE OF CASING	BRAKE HORSE POWER	MOTOR HORSE POWER	PER CENT OF MOTOR H. P. DEVELOPED	COUPLING	IMPELLER	STAGES	WT. PUMP AND MOTOR	F. O. B. DYERSBURG	DELIVERY—DAYS	
"A"	"P"	10'	220'	230'	700	6"	5"	1,800	Hor. split	64.5	75	86	Flex	Bronze	2		Yes	60	(
"B"	"P"	10'	220'	230'	700	5"	5"	1,800	Hor. split	62.6	75	84	Flex	Bronze	2		Yes	120	(
"C"	"P"	10'	220'	230'	700	5"	5"	1,800	Hor. split	55.5	75	74	Flex	Bronze	2		Yes	30	(
"D"	"R"	10'	220'	230'	700	6"	6"	1,800	Hor. split	63.0	75	84	Flex	Bronze	2		No	75	(
"E"	"S"	10'	220'	230'	700	6"	5"	1,800	Hor. split	66.0	75	88	Flex	Bronze	2		Yes	30	(
"F"	"S"	10'	220'	230'	700	6"	6"	1,800	Vert. split	53.9	75	72	Flex	Bronze	4	6,000 lbs.	No	40	90
"G"	"P"	10'	220'	230'	700	6"	6"	1,800	Hor. split	62.0	75	83	Flex	Bronze	2		Yes	45	0
"H"	"P"	10'	220'	230'	700	8"	6"	1,800	Vert. split	59.0	75	78	Flex	Bronze	2	6,300 lbs.	Yes	60	0
"I"	"Q"	10'	220'	230'	700	5"	5"	1,800	Hor. split	68.0	75	90	Flex	Bronze	2	4,000 lbs.	Yes	120	0
"J"	"S"	10'	220'	230'	700	6"	5"	1,800	Hor. split	61.5	75	81	Flex	Bronze	2		No	21	90
"K"	"S"	10'	220'	230'	700	7"	5"	1,800	Hor. split	62.0	75	83	Flex	Bronze	2		No	120	90
"L"	"S"	10'	220	230'	700	6"	6"	1,800	Hor. split	60.0	75	80	Flex	Bronze	2		Yes	60	90
"M"	"S"	10'	220'	230'	700	6"	6"	1,800	Hor. split	64.5	75	86	Flex	Bronze	2		Yes		90
"N"	"P"	10'	220'	230'	700	5"	5"	1,800	Hor. split	63.5	75	85	Flex	Bronze	2	5,390 lbs.	No		0.
"O"	"S"	10'	220'	230'	700	6"	6"	1,800	Hor. split	65.6	75	87	Flex	Bronze	2	5,400 lbs.	Yes	240	90

PLATE IV

Centrifugal pump installation for Dyersburg Water and Light Plant, Dyersburg, Tennessee, February 20

WT. PUMP AND MOTOR	F. O. B. DYERSBURG	DELIVERY—DAYS	EFFICIENCY				AVERAGE EFFICIENCY 200 TO 700 G. P. M.	PRICE OF MOTOR, PUMP AND STARTER	COST OF FOUNDATION	INSTALLATION	TOTAL COST	CHARACTERISTICS								
			Motor	Pump	Transmission	Overall						100 G. P. M.			200 G. P. M.			300 G. P. M.		
												Efficiency	Head	B. H. P.	Efficiency	Head	B. H. P.	Efficiency	Head	B. H. P.
6,000 lbs.	Yes	60	0.91	0.68	0.98	0.60	58.0	\$952.86	\$20.00	\$527.14	\$1,500.00	0.20	300	40	0.36	305	45	0.48	302	50
	Yes	120	0.91	0.65	0.98	0.58	47.5	\$1,180.00	20.00	527.14	1,727.14	0.15	258	33	0.30	258	40	0.44	258	45
	Yes	30	0.91	0.64	0.98	0.57	56.0	977.00	20.00	527.14	1,524.14	0.26			0.48		0.59			
	No	75	0.90	0.65	0.98	0.56	53.5	1,300.00	20.00	527.14	1,827.14	0.18	280	36	0.33	277	42	0.45	275	46
	Yes	30	0.90	0.66	0.98	0.58	49.0	975.00	20.00	527.14	1,522.14	0.18	294	38	0.32	290	44	0.44	288	50
	No	40	90.5	0.75	0.98	0.67	62.5	1,035.00	20.00	527.14	1,582.14	0.30	292	216	0.52	292	28	0.62	289	35
	Yes	45	0.91	0.65	0.98	0.58		969.68	20.00	527.14	1,516.82	0.26	285	27	0.39	285	34	0.50	280	42
6,300 lbs.	Yes	60	0.91	68.5	0.98	0.61	47.7	1,039.00	20.00	527.14	1,586.14	0.14	275	46	0.28	275	48	0.39	275	50
4,000 lbs.	Yes	120	0.90	0.60	0.98	0.53	46.0	1,156.85	20.00	527.14	1,703.99	0.18	272	36	0.32	270	42	0.42	267	48
	No	21	90.5	0.66	0.98	0.58	52.0	1,186.40	20.00	527.14	1,733.54	0.23	262	30	0.38	264	36	0.48	262	42
	No	120	90.5	0.65	0.98	0.58	47.5	1,226.20	20.00	527.14	1,773.34	0.21	318	40	0.36	326	45	0.47	312	50
	Yes	60	90.5	0.63	0.98	0.60	46.5	1,330.00	20.00	527.14	1,877.14	0.11	292	25	0.23	284	30	0.34	276	40
	Yes		90.5	0.63	0.98	0.56		1,022.00	20.00	527.14	1,569.14	0.18			0.30			0.40		
5,390 lbs.	No		0.91	0.64	0.98	0.57	51.0	1,244.00	20.00	527.14	1,791.14	0.16	264	20	0.38	264	34	0.49	262	40
5,400 lbs.	Yes	240	90.5	0.62	0.98	0.54	49.0	1,000.00	20.00	527.14	1,547.14	0.25	280	32	0.37	277	40	0.44	275	47

nessee, February 20, 1915. S. R. Blakeman, superintendent

CHARACTERISTIC OF PUMP VARIABLE DISCHARGES																				MOTOR CHARACTERISTIC						
100 G. P. M.		300 G. P. M.		400 G. P. M.		500 G. P. M.		600 G. P. M.		700 G. P. M.		800 G. P. M.		"R"			"S"		"P"							
Head	B. H. P.	Efficiency	Head	B. H. P.	Efficiency	Head	B. H. P.	Efficiency	Head	B. H. P.	Efficiency	Head	B. H. P.	Efficiency	Head	B. H. P.	Load	Efficiency	Pf.	Efficiency	Pf.	Efficiency	Pf.			
305	45	0.48	302	50	0.58	296	55	0.65	290	60	0.68	272	62	0.68	250	65	0.65	215	70	1						
258	40	0.44	258	45	0.52	252	49	0.58	248	53	0.64	240	58	0.64	230	63	0.50	152	61	2	88.0	81.0	88	86.0	89.0	80
		0.59			0.63			0.66			0.67			0.60						3	89.5	88.0	91	91.5	91.0	88
277	42	0.45	275	46	0.54	270	51	0.60	262	55	0.64	250	59	0.65	230	63	0.63	205	65	4	90.0	91.0	91	93.0	91.0	91
290	44	0.44	288	50	0.50	280	54	0.56	273	60	0.61	255	62	0.64	240	66	0.66	220	68	11	90.0	92.5	90	93.0	90.5	92
292	28	0.62	289	35	0.70	287	43	0.74	276	46	0.78	260	51	0.78	230	52	0.74	191	52	Voltage of Motor—2,300						
285	34	0.50	280	42	0.58	276	48	0.61	264	52	0.65	248	58	0.65	230	62	0.63	207	65	Phase 3						
275	48	0.39	275	50	0.49	270	53	0.58	262	55	0.64	252	57	0.69	230	59	0.69	218	61	Cycles 60						
270	42	0.42	267	48	0.50	260	54	0.55	255	58	0.58	245	64	0.60	230	68	0.59	210	72							
264	36	0.48	262	42	0.56	260	46	0.61	252	52	0.64	245	56	0.66	230	62	0.65	212	66							
326	45	0.47	312	50	0.56	295	53	0.61	275	57	0.63	251	59	0.65	230	62	0.63	200	64							
284	30	0.34	276	40	0.45	268	45	0.55	260	50	0.62	248	55	0.67	236	60	0.67	220	65							
		0.40			0.46			0.54			0.59			0.64			0.66									
264	34	0.49	262	40	0.56	260	44	0.61	256	54	0.63	246	60	0.64	230	63	0.60	180	58							
277	40	0.44	275	47	0.50	262	54	0.54	255	60	0.58	248	65	0.61	237	70	0.63	225	73							

tion in question care was exerted to see that the pump selected would fit the work imposed upon it. A very careful survey of all conditions was made, such as measuring the number of feet of main, the size and number of specials in the suction and discharge lines, including a survey with an engineer's level, to determine the exact elevations of all points required, no gauge records being relied upon.

The result of this survey follows:

<i>Head in discharge line</i>		<i>Feet</i>
Friction losses in 3380 feet of 10 inch C. I. pipe.....		14.26
Friction losses in 1220 feet of 12 inch C. I. pipe.....		2.08
Friction losses in 6-10 inch of C. I. ells.....		0.96
Friction losses in 10 inch suction line.....		1.27
Difference in elevation, center line of pump and low stage of river.....		18.30
Difference in elevation, center line of pump and hose of standpipe.....		132.70
Height of standpipe.....		50.00
Total head.....		219.57

To this was added 10.43 feet, an amount great enough to give all houses surrounding the standpipe a reasonable domestic pressure. In order to obtain a maximum efficiency under operating condition, a line had to be drawn, for had a pump been selected designed to furnish fire service at points located on high elevations, at the rated discharge of the pump, it would necessarily have meant that it would have to operate at a very low efficiency when pumping against ordinary pressure.

This condition had to be met and at the same time the pump had to be able to render maximum efficiency. In order to make use of the volute pump at times of fire it was proposed to pipe the two pumps so that they could be cut in series. Both being 700 gallon pumps and having similar characteristics made this condition practical. It will at once be seen that a plan of this kind would enable us to run efficiently both pumps practically all of the time and to also have two pumps available that, when run in series, were capable of giving excellent fire pressure.

INSTALLATION

Having decided upon the motor and pump, the next step was to make plans for locating and installing them. The location that presented itself that would answer the purpose without building or extending the present plant was a small room 13 x 16 feet. By locating the pump here, the suction lift was reduced to a minimum. This installation is interesting in view of the fact that no other type of pump having the same capacity could possibly have been so located. Due to the available space left in this room, and also the fact that room had to be provided for removing the piston and piston rods from the steam pump, the pump had to be located a short distance above the foundation. In the construction of this foundation, which measures 5.55 feet by 2.65 feet at the top and 3 feet by 5.55 feet at the bottom and 2.25 feet high, only 1.3 cubic yard of concrete was used, the total cost of the foundation being only \$19.97.

In the selection and installation of this pump, it was attempted in every instance to conform to the rules of the underwriters, and the pump was not contracted for until they had approved it.

The pump has a 5-inch discharge and 6-inch suction as shown on Plate IV. The discharge was increased by means of an extra heavy flanged ell at the pump to 7 inch and run from there to the 12-inch cast iron main. A 7-inch gate and check valve are located directly above the pump. This places the discharge line in a position easily reached by the engineer. The discharge line has a bypass to take care of the water meter. This meter has an extension dial flush with the engine room floor, thus making it convenient to read.

The suction lines were constructed entirely of cast iron, with cast iron specials, this construction not only gave a minimum depreciation but also reduced to a minimum the friction losses in the suction line. This line was increased to 8 inches at the pump and run practically underground all the way. Gate valves were used exclusively.

TESTS

The pump was in operation for over a month before the preliminary tests were made. Some trouble was experienced at first with packing and one of the bearings, which naturally necessitated operating it longer before making the acceptance test than would otherwise

have been necessary. Making tests of this kind in the field in small plants is quite different from laboratory experiments, where one naturally has all instruments available, as there are many obstacles to be overcome by home made devices.

The preliminary test of this pump was run on September 3, 1915, at which time, many points presented themselves for correction.

The electrical instruments used in making this test were as follows:

Voltmeter No. 10549 0 to 75 volts and 0 — 150 volts, Weston.
 Voltmeter No. 13203 0 to 75 volts and 0 — 150 volts, Weston.
 Ammeter No. 7879 0 to 25 amperes, Weston.
 Ammeter No. 9969 0 to 25 amperes, Weston.
 Wattmeter No. 333915 0 to 150 volts and 5 to 10 amperes, General Electric Company.
 Wattmeter No. 333916 0 to 150 volts and 5 to 10 amperes, General Electric Company.
 Current Transformer No. 1363343 20:1, 100 amperes, General Electric Company.
 Current Transformer No. 1363373 20:1, 100 amperes, General Electric Company.

Potential transformers on the switch board were used in the test.

The two wattmeter method of measuring the input to the motor was used, as this method would give us correct results even with considerable unbalancing in the voltage of the three phases. The sum of the two wattmeter readings gives the total power in the circuit. It will be noticed in the test data that one wattmeter reads less than the other. The following method determined whether the readings were to be subtracted or added. One wattmeter was disconnected and the other put in its place, leaving the same terminal of the voltage coil connected to the middle main and connecting the two terminals of one current coil in place of the terminals of the other current coil. The deflection of the reversed wattmeter was not reversed, therefore, the readings were added. Throughout this test no trouble was experienced from the instruments giving negative readings on light loads, and low power factors. The greatest care was exerted to see that all instruments were read accurately.

As the ratio of transformation of the current and potential transformers was 20:1, the total ratio was 400:1, when both of these instruments were used under these conditions.

By looking at the diagram of connections shown on Plate VIII,

DIAGRAM of CONNECTIONS

TEST

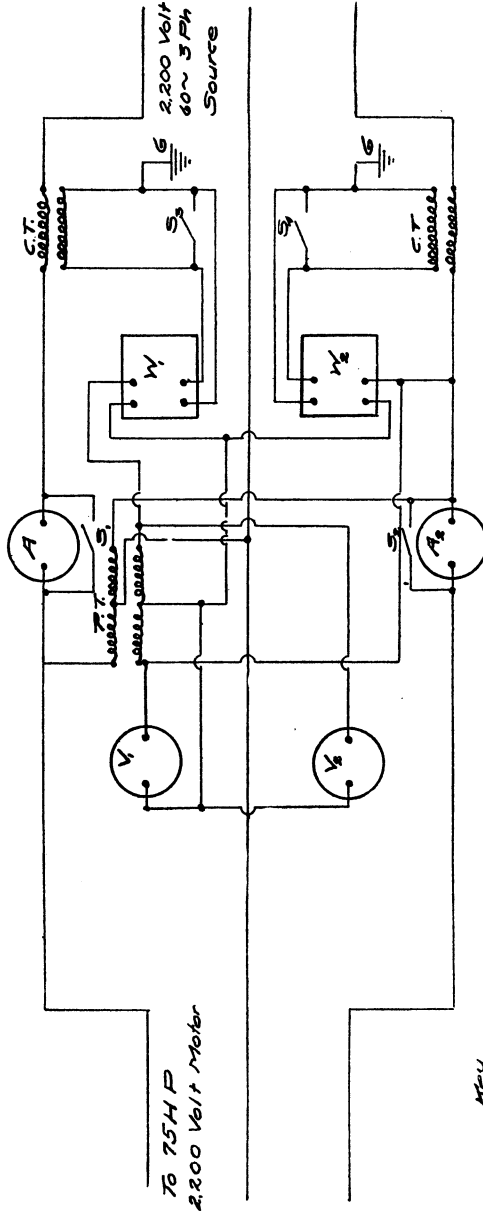
or
1,000,000 Gallon Motor Driven Centrifugal Pump

Dyersburg Water and Light Plant.

Dyersburg, Tenn.

Sept. 9, 1915.

S. R. Blakeman, Supt.



KEY

- A_1, A_2 — Ammeters
- V_1, V_2 — Voltmeters
- W_1, W_2 — Wattmeters
- AT — Potential Transformers
- C.T. — Current Transformers
- S_1, S_2, S_3 — Short Circuiting Switches
- G — Ground

it will be seen that short circuiting switches were used on both current transformers for short circuiting their secondaries before taking out an instrument. One leg of each of these secondary circuits is shown grounded, thus reducing to a minimum any danger due to handling these instruments.

The weir box was designed to handle 700 gallons per minute, with a velocity of approach not to exceed 0.70 feet per second, giving less than 0.90 feet per second at the maximum discharge of 1000 gallons per minute. Two baffles were provided as shown on Plate IX so as to have the water passing over the weir as free from eddy currents as possible. The sides and bottom of this weir box were carefully braced and tied in as shown by Plate IX. Quite an amount of trouble was experienced with this box at first, due to the settling that took place, when it was filled with water. It was, however, given more bearing surface and checked for settling with an engineer's level. These readings were taken at each end and one at the center of the box for varying depths of water.

For measuring the head of water passing over the weir, at first a glass with a scale attached was used, the zero level having been determined with an engineer's level, but this was not thought to be sufficiently accurate, so two still wells were constructed near the weir box, as shown by Plate X, with a pipe leading into the bottom of the box, this pipe being perforated with $\frac{1}{8}$ inch holes. One of the still wells was equipped with a float gauge, the other being equipped with a hook gauge. This consisted of a $\frac{1}{4}$ inch steel rod with a small pointer attached and a long thread and nut at the top. The readings being taken from a scale, made a part of the still well. The zero readings of these gauges were determined by using an engineer's level.

These two gauges were used as checks on each other. At first, a rectangular notch weir was designed, having a width of 23.6 inches and a height of 14 inches, this being so designed as to take care of a maximum discharge of 1000 gallons per minute. The greatest care was used in the construction of this notch, the sides being made exactly at right angles to the horizontal, having a bevel of 2.25 inches, thus giving the angle of the bevel 22 degrees. This was made from one solid piece of timber, well seasoned, and free from warps the bevel was lined with metal. A detailed drawing of this notch is shown on Plate IX. The piece of timber containing this notch was carefully levelled and fastened to the weir box with

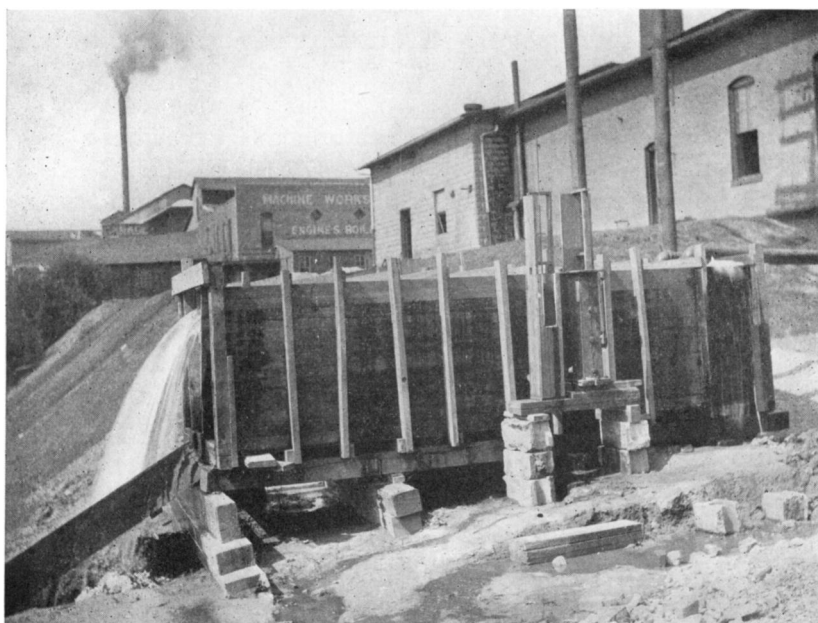


PLATE IX

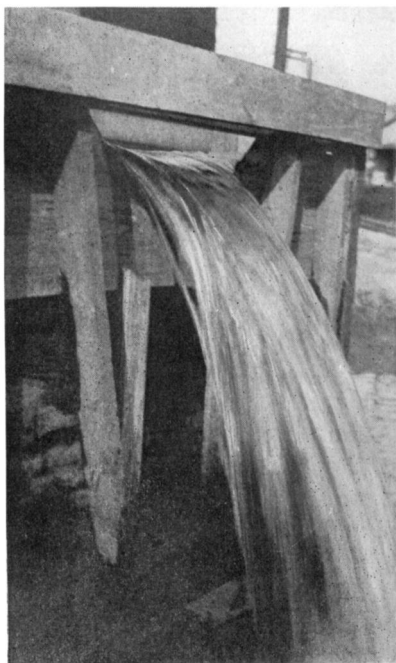


PLATE VI

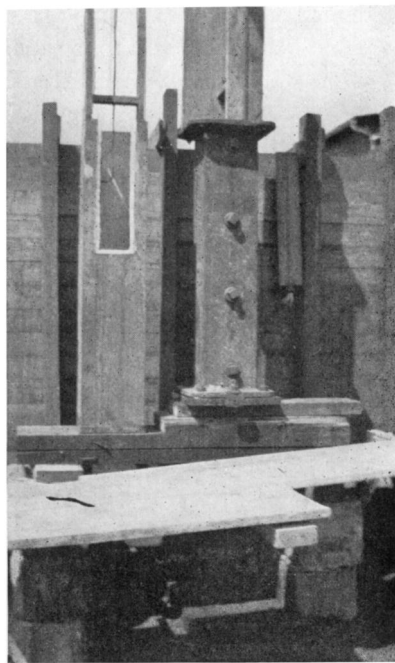


PLATE X

wood screws. Before any tests were made with this notch, the zero point of it was carefully located with reference to the hook gauge. In the calculations made this notch was treated as one having complete and perfect contraction. The following formula being used in arriving at the results:

$$Q^3 = u \times \frac{2}{3} \times b \times h \sqrt{2 \times g \times h}$$

where

Q = cubic feet per second.

b = width of weir in feet

h = height of weir in feet.

g = 32.2

u = a constant, see table.

The table of constants being as follows:

For b = 0.60 or 23.6 inches

h	<i>Inches</i>	u
2.36		0.618
3.15		0.613
3.93		0.609
4.75		0.605
5.90		0.600
7.90		0.592
11.18		0.586
15.70		0.586
19.70		0.586
23.60		0.585

The data obtained from the use of this type of weir tests were not relied upon, or used in the final characteristics obtained, for it was thought that these results were not sufficiently accurate, due to the small volume of water measured. However, the original and calculated data obtained from these tests are included in this report, also platted curves giving an idea as to how they compared with the other tests made.

As the maximum discharge for which this pump was to be tested was 1000 gallons per minute, it was decided to make use of the 90 degree V notch weir, shown on Plate IX, this weir having a depth of 1.2 feet and a width at the top of 2.4 feet, the bevel being the same as used on the rectangular notch weir, this was also designed to take care of a maximum discharge of 1000 gallons per minute.

By using the V notch weir the coefficient of discharge remains constant, a feature not met with in the other weir, it remaining constant from a small head on the apex of the notch to a maximum

which the triangular notch will discharge. Also the ratio of the depth to width is a constant, therefore the influence of end contraction is constant. This type of notch also has the advantage that at small flows, the variations in head are rapid, thus giving a good percentage of accuracy.

In obtaining the zero level of this notch, a very fine piece of metal was made that would just fit into the notch, then just ahead of the pointer a piece of window glass was placed, sealed against leakage. The water was then raised in the weir box until the top of the water

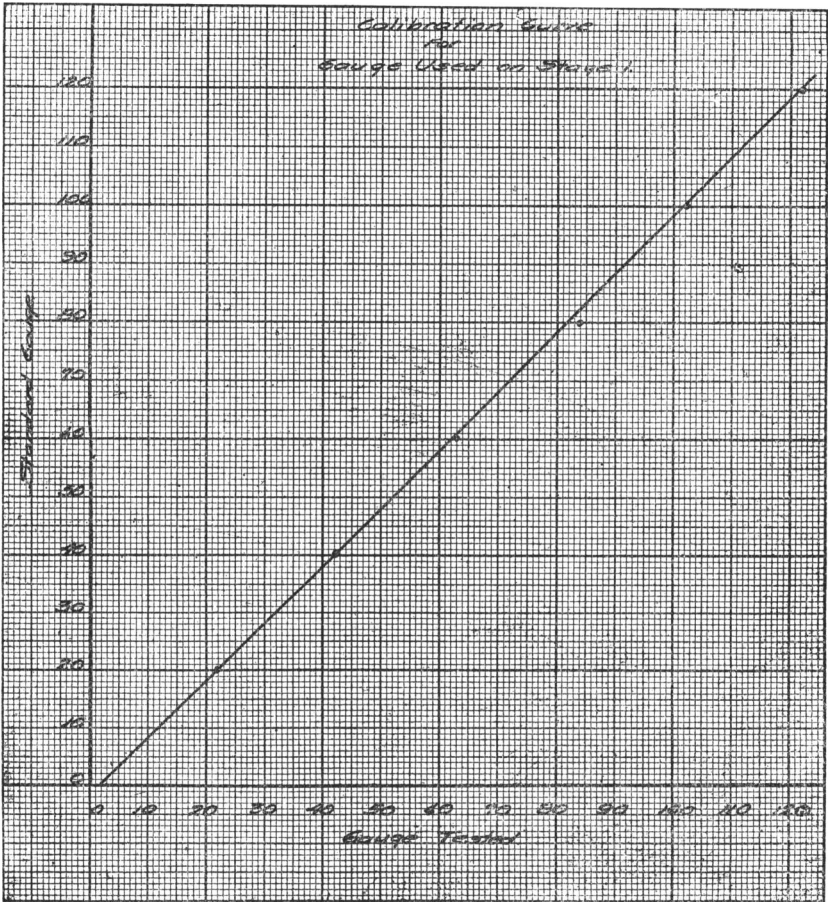


PLATE XI

was level with the top of the pointer. At this point, readings were made on both hook and float gauges. From these readings the length of the pointer was deducted, thus giving us the zero level. It will be noticed in all of the data compiled that both the hook and float gauges checked. Just before using the float gauge, it was given a light tap, so as to avoid any error in reading due to its being stuck. The glass gauge was ignored. All readings were taken in feet.

In making corrections for head due to clear well, a float gauge was used, so arranged as to be read above the filter room floor. The difference in elevation of the pump suction and the bottom of the clear well was determined with an engineer's level.

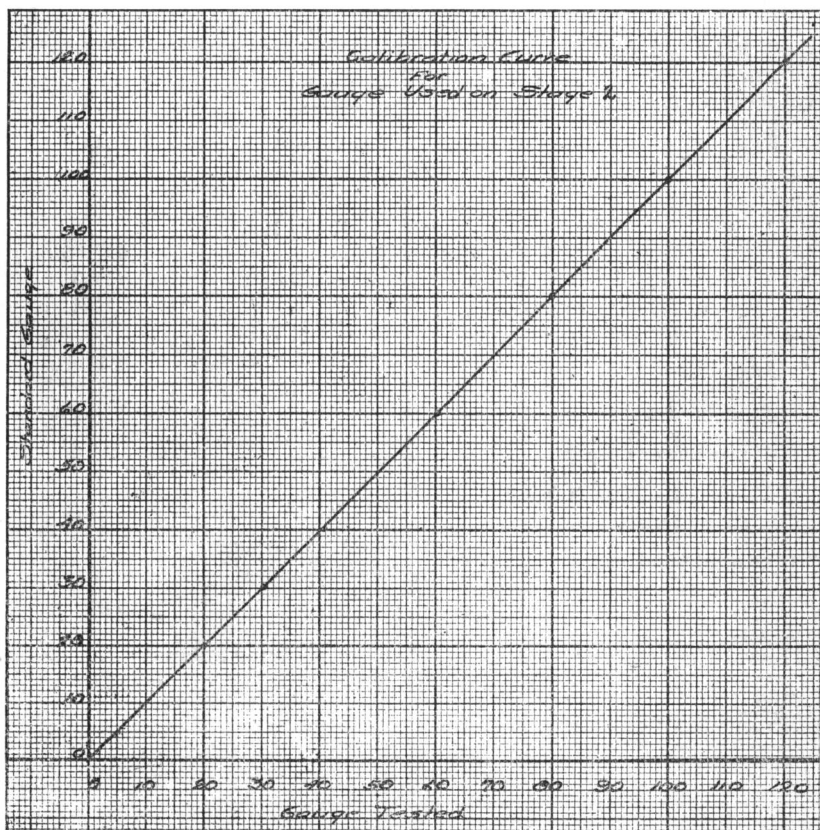


PLATE XII

The pressures in stages one and two were measured with two Ashton gauges, the calibration curve for these gauges is shown on Plates XI and XII. All readings made in this test were made at practically the same time, thereby reducing errors to a minimum.

The calculations made, are shown by following through those for test No. 1, with the 90 V notch weir.

(1) Average volts secondary	$= \frac{115.5 \text{ and } 114}{2}$	$= 114.7$
(2) Average volts primary	$= 114.7 \times 20$	$= 2294$
(3) Total wattmeter readings	$= 86 \text{ and } 41$	$= 127$
(4) Total watts input	$= 127 \times 400$	$= 50,800$
(5) Total k.w. input	$= \frac{50,800}{1,000}$	$= 50.8$
(6) Total h.p. input	$= \frac{50.8}{746}$	$= 67.5$
(7) Average current	$= \frac{15.2 \text{ and } 12.3}{2}$	$= 13.7$
(8) Power factor	$= \frac{\text{Watts input}}{\text{Voltage} \times \text{current} \times 50,800}$	$= \sqrt{3}$
or power factor	$= \frac{-2294.0 \times 13.7 \times 1.73}{50,800}$	$= 0.94$
(9) Head in feet	$= 55 \times 2.31$	$= 127.05$
(10) Head corrected	$= 127,105 - 7.23$	$= 119.8$
(11) Hook gauge inches	$= 0.95 \times 12$	$= 11.4$
(12) Gallons per minute	$= 0.305 H \sqrt{H} \times 7.5$ $= 0.305 \times 114.4 \times 11.4 \times 7.5$ $= 1001.2 \text{ G.P.M.}$	$\sqrt{11.4}$
(13) Pounds of water	$= 1001 \times 8.33$	$= 8,343.3$
(14) Horse power output	$= \frac{8345.3 \times 119.8}{33,000}$	$= 30.3$
(15) Efficiency of motor from characteristic		$= 0.88$
(16) Overall efficiency	$= \frac{\text{Horse power output}}{\text{Horse power input}}$ $= \frac{30.3}{67.5}$	$= 45\%$
(17) Brake horse power	$= \text{Efficiency of Motor} \times \text{Input}$ $= 0.88 \times 67.5$	$= 59.4$
(18) Efficiency of pump	$= \frac{\text{Overall efficiency}}{\text{Motor efficiency}}$ $= \frac{45}{0.88}$	$= 51\%$

The formula for figuring the discharge through the rectangular notch weir has already been given. In the latter part of this report

will be found data sheets showing the original data, and also the calculated results of three tests made in the plant, two making use of the 90 V notch and one using the rectangular notch weir, also the data as furnished by the makers, showing the results obtained from their tests. Following these data sheets will be found the characteristic curve sheets, which are self explanatory.

On each of these characteristic curve sheets there is plotted three different sets of curves, viz, head-capacity, efficiency and brake horse power for the guaranteed curves, before the pump was actually built, the curves obtained on the shop test and the curves obtained from data compiled from the acceptance test. Two of these characteristic curves were obtained from data obtained from the V notch weir in the plant.

It is interesting to note how the guaranteed characteristics were exceeded, as shown by the efficiency curve, and how close the shop test and acceptance test efficiency curve check.

After these data were worked up and curves were plotted, showing that the guaranteed efficiency had been exceeded, a recommendation was made that the unit be accepted. The writer has never before made an acceptance test where the manufacturers guarantee was so completely fulfilled as in this test. All new equipment purchased for our plant is bought under similar guarantees.

After the acceptance tests had been completed, comparative coal tests were made between the steam actuated pump, formally used, and the turbine pump. The results obtained upon this test are shown on Plate XIX. By glancing at these data, the saving in coal between the steam pump and the turbine pump is easily seen.

CONCLUSION

Since the installation of this pump, it has been possible to cut out one boiler for a great part of the day. It has been in operation for nearly eight months, pumping all the water used in Dyersburg, without a single charge for maintenance.

This pump, when given the "Underwriters Test" fulfilled it in every way.

PLATE XIX

Comparative coal tests, steam and Centrifugal Pumps. Dyersburg Water and Light Plant, Dyersburg, Tenn.

TEST NO.	K.W.H. GENE-RATED	GAL-LONS OF WATER PUMPED 24 HOURS	POUNDS OF COAL USED	TONS OF COAL USED	PUMP ON	KIND OF COAL	BOILERS ON	DATE
1	2,260	595,410	19,224	9.61	Centrifugal	Nut, pea and slack	4 and 5	Sept. 29, 1915
2	2,200	584,025	18,690	9.34	Centrifugal	Mine run	4 and 5	Oct. 1, 1915
3	1,690	597,675	21,093	10.54	Steam	Mine run	4 and 5	Oct. 2, 1915
4	2,090	540,225	16,287	8.14	Centrifugal	Mine run	4 and 5	Oct. 3, 1915
5	1,720	526,575	19,758	9.87	Steam	Mine run	4 and 5	Oct. 4, 1915
6	1,640	510,525	25,165	12.58	Steam	Nut, pea and slack	1, 2 and 3	Oct. 13, 1915
7	1,680	546,525	25,365	12.68	Steam	Nut, pea and slack	1, 2 and 3	Oct. 14, 1915
8	2,140	561,975	21,894	10.94	Steam	Mine run	1, 2 and 3	Oct. 12, 1915

PLATE XXI

Original data. Acceptance test of 1,000,000 gallon motor driven centrifugal pump. Dyersburg Water and Light Plant, Dyersburg, Tennessee, September 9, 1915.

TEST NO.	VOLTMETER		WATT-METER		AMMETER		GAUGE POUNDS		CLEAR WELL HEAD FEET	WEIR HEADS IN FEET			SPEED IN R. P. M.
	No. 1	No. 2	No. 1	No. 2	No. 1	No. 2	Stage 1	Stage 2		Hook	Float	Glass	
1	115.5	114.0	86.0	41.0	15.2	12.3	30	55	7.23	0.95	0.95		1710
2	115.0	114.0	90.0	35.0	15.8	12.8	30	63	10.40	0.92	0.92	0.84	1680
3	115.0	114.0	87.5	35.0	15.4	12.3	40	74	9.55	0.89	0.89	0.81	1700
4	115.0	114.0	85.0	32.5	15.1	12.0	48	83	9.00	0.87	0.87	0.79	1700
5	115.0	114.0	82.5	30.0	14.7	11.4	50	94	8.45	0.82	0.82	0.74	1740
6	115.0	114.0	80.0	27.5	14.3	10.9	54	102	8.05	0.78	0.78	0.71	1740
7	115.0	114.0	75.0	25.0	13.5	10.2	59	112	7.70	0.72	0.72	0.64	1738
8	115.0	114.0	72.5	25.0	13.0	10.1	60	114	7.40	0.70	0.70	0.63	1743
9	115.0	114.0	65.0	17.5	12.1	8.9	63	120	7.05	0.62	0.62	0.55	1751
10	115.0	114.0	44.0	20.0	3.4	6.0	60	110		0	0	0	1740

Type of weir—90° V notch

PLATE XXII

Calculated data. Acceptance test of 1,000,000 gallon motor driven centrifugal pump. Dyersburg Water and Light Plant, Dyersburg, Tennessee, September 9, 1915

TEST NO.	AVE. VOLTS, SECONDARY	AVE. VOLTS, PRIMARY	WATTMETER, TOTAL	WATTS, TOTAL	K.W. INPUT	POWER FACTOR	H.P. INPUT	SPEED, R.P.M.	AVERAGE CURRENT	HEAD, FEET	HOOK GAUGE, FEET	HOOK GAUGE, INCHES	G.P.M.	POUNDS OF WATER	H.P. OUTPUT	MOTOR EFFICIENCY	OVERALL EFFICIENCY	PUMP EFFICIENCY, %	B.H.P.
1	114.7	2295	127	50800	50.8	0.94	67.5	1710	13.7	119.8	0.95	11.4	1001.2	8343.3	30.3	0.88	0.45	51.1	59.4
2	114.5	2290	125	50000	50.0	0.88	66.6	1680	14.3	145	0.92	11.0	913.3	7611.2	33.3	0.88	0.50	56.8	58.6
3	114.5	2290	122.5	49000	49.0	0.89	65.3	1700	13.8	172	0.89	10.7	837.6	6980.0	36.3	0.88	0.55	62.0	57.4
4	114.5	2290	117.5	47000	47.0	0.87	62.6	1700	13.5	190	0.87	10.4	797.2	6643.0	38.2	0.88	0.61	69.3	55.0
5	114.5	2290	112.5	45000	45.0	0.87	60.0	1740	13.0	215	0.82	9.8	686.5	5721.0	37.2	0.88	0.62	70.4	52.8
6	114.5	2290	107.5	43000	43.0	0.86	57.3	1740	12.6	235	0.78	9.3	600.9	5008.0	35.6	0.88	0.62	70.4	50.2
7	114.5	2290	100.0	40000	40.0	0.85	53.3	1738	11.8	259	0.72	8.6	493.7	4114.3	32.3	0.88	0.60	68.1	46.9
8	114.5	2290	97.5	39000	39.0	0.85	52.0	1743	11.5	262	0.70	8.4	451.8	3765.5	29.9	0.88	0.57	64.7	45.7
9	114.5	2290	82.5	33000	33.0	0.79	44.0	1751	10.5	277	0.62	7.4	343.8	2865.0	24.0	0.88	0.50	56.8	38.7
10	114.5	2290	46.0	18400	18.4	0.60	24.5	1740	7.7	254	0	0	0	0	0	0.88	0		21.5

Type of weir—90° V notch

PLATE XXIV

Original data. Acceptance test of 1,000,000 gallon motor driven centrifugal pump. Dyersburg Water and Light Plant, Dyersburg, Tennessee, September 10, 1915.

TEST NO.	VOLTMETER		WATT-METER		AMMETER		GAUGE POUNDS		CLEAR WELL HEAD FEET	WEIR HEADS IN FEET			SPEED IN R. P. M.
	No. 1	No. 2	No. 1	No. 2	No. 1	No. 2	Stage 1	Stage 2		Hook	Float	Glass	
1	115.0	114.0	92.0	47.5	16.0	14.4	37	57	6.88	0.940	0.940	1.33	1685
2	115.5	114.0	94.0	42.5	16.4	13.6	43	74	7.08	0.915	0.915	1.31	1710
3	115.5	114.0	90.0	42.5	15.9	13.2	47	82	6.85	0.890	0.890	1.29	1711
4	115.5	114.0	85.0	40.0	15.1	12.5	52	93	6.68	0.845	0.845	1.25	1716
5	115.5	114.0	82.5	35.0	14.6	12.0	56	102	6.60	0.810	0.810	1.21	1717
6	115.5	114.0	77.5	30.0	13.9	10.9	60	112	6.53	0.740	0.740	1.15	1730
7	115.5	114.0	75.0	30.0	13.5	10.5	61	114	6.58	0.725	0.725	1.13	1740
8	115.5	114.0	72.5	30.0	13.3	10.4	62	115	6.60	0.710	0.710	1.15	1740
9	115.5	114.0	70.0	26.0	12.8	9.8	64	118	6.68	0.675	0.675	1.08	1743
10	116.0	114.0	65.0	22.5	12.1	8.8	66	123	6.83	0.620	0.620	1.02	1749
11	115.0	114.0	42.5	4.0	9.0	6.4	60	110		0	0	0	1740

Type of weir—90° V notch

PLATE XXV

Calculated data. Acceptance test of 1,000,000 gallon motor driven centrifugal pump. Dyersburg Water and Light Plant, Dyersburg, Tennessee, September 10, 1915

TEST NO.	AVE. VOLTS, SECONDARY	AVE. VOLTS, PRIMARY	WATTMEYER, TOTAL	WATTS, TOTAL	K.W. INPUT	POWER FACTOR	H.P. INPUT	SPEED, R.P.M.	AVERAGE CURRENT	HEAD, FEET	HOOK GAUGE, FEET	HOOK GAUGE, INCHES	G.P.M.	POUNDS OF WATER	H.P. OUTPUT	MOTOR EFFICIENCY	OVERALL EFFICIENCY	PUMP EFFICIENCY, %	B.H.P.	HEAD IN FEET, CORRECTED
1	114.5	2290	139.5	55800	55.8	.92	74.4	1685	15.2	132.8	.94	11.28	974.8	8123.5	31.0	.88	.41	46.5	65.4	126
2	114.5	2290	136.5	54600	54.6	.91	72.8	1710	15.0	171.4	.915	11.03	938.0	7816.8	38.9	.88	.53	60.0	64.0	164
3	114.5	2290	132.5	53000	53.0	.90	70.6	1711	14.5	190.3	.89	10.68	834.6	6955.5	38.6	.88	.54	61.3	62.1	183
4	114.5	2290	125.0	50000	50.0	.90	66.6	1710	13.8	215.5	.845	10.14	746.2	6218.3	39.3	.88	.59	67.0	58.6	209
5	114.5	2290	117.5	47000	47.0	.89	62.6	1717	13.3	235.6	.81	9.72	562.6	5580.0	33.7	.88	.61	69.3	55.0	229
6	114.5	2290	107.5	43000	43.0	.87	57.3	1730	12.4	258.0	.74	8.88	522.7	4355.8	33.1	.88	.57	64.7	50.4	251
7	114.5	2290	105.0	42000	42.0	.88	56.0	1740	12.0	262.8	.725	8.7	501.7	4180.8	32.4	.88	.57	65.6	49.2	256
8	114.5	2290	102.5	41000	41.0	.87	54.6	1740	11.8	265.6	.71	8.52	480.7	4005.8	31.4	.88	.57	65.3	48.0	259
9	114.5	2290	96.0	38400	38.4	.78	51.6	1743	12.3	272.5	.675	8.1	420.0	3500.0	28.1	.88	.54	61.8	45.4	266
10	115.0	2300	87.5	35000	35.0	.84	46.6	1749	10.4	282.9	.62	7.44	341.2	2843.0	23.7	.88	.50	56.8	41.0	276
11	114.5	2290	46.5	18600	18.6	.60	24.8	1740	7.7	254.1	0	0	0	0		.88		21.8		

Type of weir—90° V notch

PLATE XXVII

Original data. Acceptance test of 1,000,000 gallon motor driven centrifugal pump. Dyersburg Water and Light Plant, Dyersburg, Tennessee, September 17, 1915.

TEST NO.	VOLTMEYER		WATT-METER		AMMETER		GAUGE POUNDS		CIPAR WELL HEAD FEET	WEIR HEADS IN FEET			SPEED IN R. P. M.
	No. 1	No. 2	No. 1	No. 2	No. 1	No. 2	Stage 1	Stage 2		Hook	Float	Glass	
1	115.0	113.5	98.0	49.0	17.3	14.5	55.0	35	6.75	0.510	0.510	0.880	1710
2	115.5	113.5	88.0	44.0	15.6	12.9	62.9	33	7.98	0.485	0.485	0.860	1730
3	115.0	113.5	87.5	40.0	15.5	12.4	74.2	39	7.53	0.460	0.460	0.830	1745
4	115.0	113.5	85.0	35.0	15.1	11.6	82.4	43	7.23	0.435	0.435	0.810	1760
5	115.0	114.0	88.0	42.5	15.5	13.0	93.3	53	3.23	0.420	0.420	0.785	1765
6	115.5	113.5	80.0	37.5	14.4	11.5	102.0	57	3.48	0.380	0.380	0.750	1760
7	115.0	113.5	77.0	35.0	13.8	10.7	112.0	59	3.63	0.339	0.339	0.710	1765
8	115.0	113.5	75.0	34.0	13.4	10.9	115.0	60	3.83	0.328	0.328	0.700	1775
9	115.0	113.5	72.5	35.0	13.1	10.6	118.0	62	3.98	0.315	0.315	0.690	1790
10	115.5	113.5	63.0	27.5	11.7	9.1	123.7	64	4.43	0.245	0.245	0.610	1790
11	115.0	113.5	41.0	10.0	9.0	9.6	110.0	60	4.43	0.000	0.000	0.000	1787

Type of weir—Rectangular notch
Height = 14 inches. Width 23.6 inches

PLATE XXVIII

Calculated data. Acceptance test of 1,000,000 gallon motor driven centrifugal pump. Dyersburg Water and Light Plant, Dyersburg, Tennessee, September 17, 1915

TEST NO.	AVE. VOLTS, SECONDARY	AVE. VOLTS, PRIMARY	WATTMETER, TOTAL	WATTS, TOTAL	K.W. INPUT	H.P. INPUT	AVERAGE CURRENT	POWER FACTOR	SPEED, R.P.M.	HEAD IN FEET	HEAD, IN FEET, CORRECTED	HOOK GAUGE, FEET	G.P.M.	POUNDS OF WATER	H.P. OUTPUT	OVERALL EFFICIENCY	EFFICIENCY MOTOR	PUMP EFFICIENCY
1	114.50	2290	147.0	58800	58.8	78.4	15.90	0.90	1710	127.05	120.32	0.510	1031.4	8595.0	31.3	39.9	0.88	45.3
2	114.25	2285	132.0	52800	52.8	70.4	14.25	0.93	1730	145.29	137.31	0.485	954.0	7970.0	33.1	47.0	0.88	53.4
3	114.25	2285	127.5	51000	51.0	69.0	13.95	0.92	1745	171.40	163.87	0.460	868.5	7237.5	35.9	52.0	0.88	59.0
4	114.50	2290	120.0	48000	48.0	64.0	13.35	0.91	1765	190.34	183.11	0.435	805.5	6712.5	37.2	58.1	0.88	66.0
5	114.50	2290	130.5	52200	52.2	69.6	14.25	0.92	1760	215.52	212.29	0.420	765.0	6375.0	41.0	58.9	0.88	67.0
6	114.25	2285	117.5	47000	47.0	62.0	12.95	0.91	1765	235.60	232.14	0.380	639.0	5325.0	37.1	59.8	0.88	68.0
7	114.25	2285	112.0	44800	44.8	59.7	12.25	0.92	1765	258.70	255.09	0.339	544.5	4537.5	35.0	58.6	0.88	66.5
8	114.25	2285	109.0	43600	43.6	58.1	12.15	0.94	1775	265.65	261.82	0.328	527.8	4398.75	34.9	60.0	0.88	68.0
9	114.50	2290	107.5	43000	43.0	57.0	11.85	0.92	1790	272.58	268.60	0.315	497.2	4143.3	33.7	59.0	0.88	67.0
10	114.25	2285	90.5	36200	36.2	48.2	10.40	0.885	1790	285.74	281.31	0.245	335.3	2794.3	23.8	49.3	0.88	56.0
11	114.25	2285	51.0	20400	20.4	27.2	9.30	0.55	1787	254.10	249.76	0	0	0			0.88	

Type of weir—Rectangular notch

Height 14 inches. Width 23.6 inches

